floods would inundate as well as the inundation area for the most conservative (highest) of the estimated maximum floods. As indicated on the figure, the partial or discontinuous inundation areas in Midway Valley Wash and the upper reaches of Drill Hole Wash are based on the probable maximum flood values derived in accordance with guidelines of the American National Standards Institute and American Nuclear Society; for other areas, the most extensive flood zones are based on the regional maximum flood levels listed in Table 3-9. The figure also shows that all floods along Fortymile Wash and Yucca Wash would remain within existing stream channels.

Table 3-9. Estimated peak discharges along washes at Yucca Mountain.[a]

Name	Drainage area (square kilometers)[b]	Peak discharge 100-year flood (cubic meters per second)[c]	Peak discharge 500-year flood (cubic meters per second)	Regional maximum flood (cubic meters per second)
Fortymile Wash	810	340	1,600	15,000
Busted Butte (Dune) Wash	17	40	180	1,200
Drill Hole Wash[d]	40	65	280	2,400
Yucca Wash	43	68	310	2,600

a. Source: DIRS 102783-Squires and Young (1984, p. 2).
b. To convert square kilometers to square miles, multiply by 0.3861.
c. To convert cubic meters to cubic feet, multiply by 35.314.
d. Includes Midway Valley and South Portal Washes as tributaries—North and South Portal Areas.

Along Busted Butte (Dune) and Drill Hole Washes, the *500-year flood* would exceed stream channels at several places, and the probable maximum flood would inundate broad areas in Midway Valley Wash near the North Portal. None of the identified flood estimates predicts water levels high enough to reach either the North or South Portal opening to the subsurface facilities (DIRS 100530-Blanton 1992, pp. 4 and 7), which would be at either end of the Exploratory Studies Facility tunnel shown in the figure.

The U.S. Geological Survey (DIRS 103469-Thomas, Hjalmarson, and Waltemeyer 1997, all) recently published a revised methodology for calculating peak flood discharges in the southwestern United States. A preliminary evaluation indicates that the methodology, if appropriate for use, could result in estimates for 100-year floods that are larger than those listed in Table 3-8 and shown in Figure 3-12. However, the new methodology affects only the 100-year flood estimate, so discharge numbers and expanded inundation lines resulting from its use would be within the bounds set by the 500-year flood.

DOE has prepared a *floodplain* assessment for the Proposed Action in accordance with the requirements of 10 CFR Part 1022. Appendix L contains the floodplain assessment.

Surface-Water Quality. Samples of stream waters in the Yucca Mountain region have been collected and analyzed for their general chemical characteristics. Because surface-water flows are rare and in immediate response to storms, data from sampling events are sparse. Results of the surface-water sample analyses (Table 3-10) bear some resemblance to those from groundwater samples, as discussed in Section 3.1.4.2.2, because both contain bicarbonate as a principal component. However, in general, the groundwaters have a higher mineral content, suggesting more interaction between rock and water (see Section 3.1.4.2.2, Tables 3-13 and 3-17).

3.1.4.2 Groundwater

This section discusses groundwater, first on a regional basis and then in the Yucca Mountain vicinity. Many studies have been conducted on the groundwater system under and surrounding Yucca Mountain. These studies provide a firm basis of understanding of the hydrology of the region. However, because

Table 3-10. Chemistry of surface water in the Yucca Mountain region.[a]

Chemical[b]	Range of chemical composition
pH	7.8 - 8.4
Total dissolved solids (milligrams per liter)	45.0 - 123
Calcium (milligrams per liter)	6.7 - 28.0
Magnesium (milligrams per liter)	0.7 - 3.9
Potassium (milligrams per liter)	3.2 - 11.0
Sodium (milligrams per liter)	2.4 - 16.0
Bicarbonate (milligrams per liter)	32.0 - 109
Chloride (milligrams per liter)	1.3 - 10.0
Sulfate (milligrams per liter)	4.1 - 24.0
Silica (milligrams per liter)	4.5 - 36.0

a. Source: DIRS 151945-CRWMS M&O (2000, Table 5.3-3, p. T5.3-7).
b. Based on 18 samples from 15 different surface-water locations (12 involve a single sampling event and 3 involve two sampling events) collected from 1984 to 1995. One milligram per liter is equivalent to one part per million.

groundwater systems are complex and difficult to study, there are differences of opinion among experts related to interpreting available data and describing certain aspects of the Yucca Mountain groundwater system. Therefore, this section also discusses the various views on the groundwater system under Yucca Mountain, where viewpoints differ.

3.1.4.2.1 *Regional Groundwater*

The groundwater flow system of the Death Valley region is very complex, involving many *aquifers* and confining units. Over distance, these layers vary in their characteristics or even their presence (DIRS 151945-CRWMS M&O 2000, pp. 9.2-5 to 9.2-10). In some areas confining units allow considerable movement between aquifers; in other areas confining units are sufficiently impermeable to support artesian conditions (where water in a lower aquifer is under pressure in relation to an overlying confining unit; when intersected by a well, the water will rise up the borehole).

In general, the principal water-bearing units of the Death Valley regional groundwater flow system (or simply Death Valley region) are grouped in three types of saturated hydrogeologic units: basin-fill alluvium (or alluvial aquifer), volcanic aquifers, and carbonate aquifers (DIRS 151945-CRWMS M&O 2000, pp. 9.2-23 and 9.2-24). An alluvial aquifer is in a *permeable* body of sand, silt, gravel, or other detrital material deposited primarily by running water. Volcanic and carbonate aquifers are in permeable units of *igneous* (of volcanic origin) and carbonate (limestone or dolomite) rock, respectively. The mountainous area that makes up the north-central portion of the Death Valley region that includes the Yucca Mountain area is often underlain by volcanic rocks and associated volcanic aquifers. The valley or basin areas to the south and southeast of Yucca Mountain contain alluvial aquifers, including those beneath the Amargosa Desert. Carbonate aquifers are regionally extensive and generally occur at large depths below volcanic aquifers or alluvial aquifers (DIRS 151945-CRWMS M&O 2000, p. 9.6-2). The discussion of groundwater at Yucca Mountain describes the position of the various aquifers and confining units in relation to each other and to stratigraphic units.

The alluvial aquifers below the Amargosa Desert receive underflow (groundwater movement from one area to another) from groundwater basins to the north as well as from basin areas to the east and, therefore, contain a mixture of water from several different aquifers (DIRS 151945-CRWMS M&O 2000, pp. 9.2-16 to 9.2-18). For example, the volcanic aquifers beneath Yucca Mountain are believed to provide inflow to the alluvial aquifers beneath the Amargosa Desert. In addition, the springs in the Ash Meadows area are fed in part by the carbonate aquifers (DIRS 101167-Winograd and Thordarson 1975, p. C53) and what is not discharged through the springs flows into groundwater moving through the alluvial aquifers at the southeast end of the Amargosa Desert and then discharges at Alkali Flat (Franklin Lake Playa) or continues as groundwater into Death Valley (DIRS 151945-CRWMS M&O 2000, pp. 9.2-17 and 9.2-18). There is also evidence that indicates a carbonate aquifer might be present below the volcanic sequence, extending from eastern Yucca Mountain south into the Amargosa Desert (DIRS 100465-Luckey et al. 1996, pp. 32 and 40).

HYDROGEOLOGIC TERMS

Permeability: Describes the ease or difficulty with which water passes through a given material. Permeable materials allow fluids to pass through readily, while less permeable materials inhibit the flow of fluids.

Aquifer: A permeable water-bearing unit of rock or sediment that yields water in a usable quantity to a well or spring.

Saturated zone: The area below the water table where all spaces (fractures and rock pores) are completely filled with water.

Confining unit (or aquitard): A rock or sediment unit of relatively low permeability that retards the movement of water in or out of adjacent aquifers.

Inflow: Sources of water flow into a groundwater system such as surface infiltration (recharge) or contributions from other aquifers.

Basins. The Death Valley regional groundwater flow system (Figure 3-13) or region covers about 50,000 square kilometers (19,000 square miles) (DIRS 151945-CRWMS M&O 2000, p. 9.2-3). Straddling the Nevada-California border, this flow system includes several prominent valleys (Amargosa Desert, Pahrump Valley, and Death Valley) and their separating mountain ranges and extends north to the Kawich Valley, encompassing all of the Nevada Test Site (DIRS 151945-CRWMS M&O 2000, Figures 9.2-1 and 9.2-2, pp. F9.2-1 and F9.2-2). The major recharge areas are mountains in the east and north portions of the region (DIRS 151945-CRWMS M&O 2000, pp. 9.2-11 and 9.2-15). The discharge points are primarily to the south and include the southernmost discharge points in Death Valley and intermediate points such as Ash Meadows in the Amargosa Desert and Alkali Flat (DIRS 151945-CRWMS M&O 2000, p. 9.2-13). Therefore, flow is primarily to the west or south. Figure 3-13 shows a slightly reduced outline for the regional flow system that some Yucca Mountain Site Characterization Project modeling efforts (for example, DIRS 100131-D'Agnese et al. 1997, all) have used as the boundary. This reduced area is divided into the Northern, Central, and Southern Death Valley subregions. The Central Death Valley subregion contains the area of Yucca Mountain.

Hydrologic investigations of the Death Valley region date back to the early 1900s, with early work performed primarily by the U.S. Geological Survey (DIRS 100131-D'Agnese et al. 1997, p. 4). More recently, studies by both the U.S. Geological Survey and the State of Nevada have included efforts to collect and compile water-level data from regional wells (DIRS 151945-CRWMS M&O 2000, p. 9.2-39). DOE has collected groundwater-level data from wells at Yucca Mountain and in neighboring areas on a routine basis since 1983, and has used the levels to which water rises in these wells—called the *potentiometric surface*—to map the slope of the groundwater surface and to determine the direction of flow. Figure 3-14 is a potentiometric surface map of the Death Valley regional groundwater flow system. Based on these and other data, groundwater in aquifers below Yucca Mountain and in the surrounding region flows generally south toward discharge areas in the Amargosa Desert and Death Valley (Figure 3-15). The area around Yucca Mountain is in the central subregion of the Death Valley region, and this subregion has three groundwater basins: (1) Ash Meadows, (2) Alkali Flat-Furnace Creek, and (3) Pahute Mesa-Oasis Valley (DIRS 102893-Rush 1971, pp. 10 and 11; DIRS 101062-Waddell 1982, pp. 13 to 20; DIRS 100465-Luckey et al. 1996, pp. 28-30; and DIRS 100131-D'Agnese et al. 1997, p. 65). The aquifers below Yucca Mountain have been included in the Alkali Flat-Furnace Creek groundwater basin because of evidence that the groundwater discharges mainly at Alkali Flat (Franklin Lake Playa) and potentially to the Furnace Creek Wash area of Death Valley (DIRS 151945-CRWMS M&O 2000, p. 9.2-18).

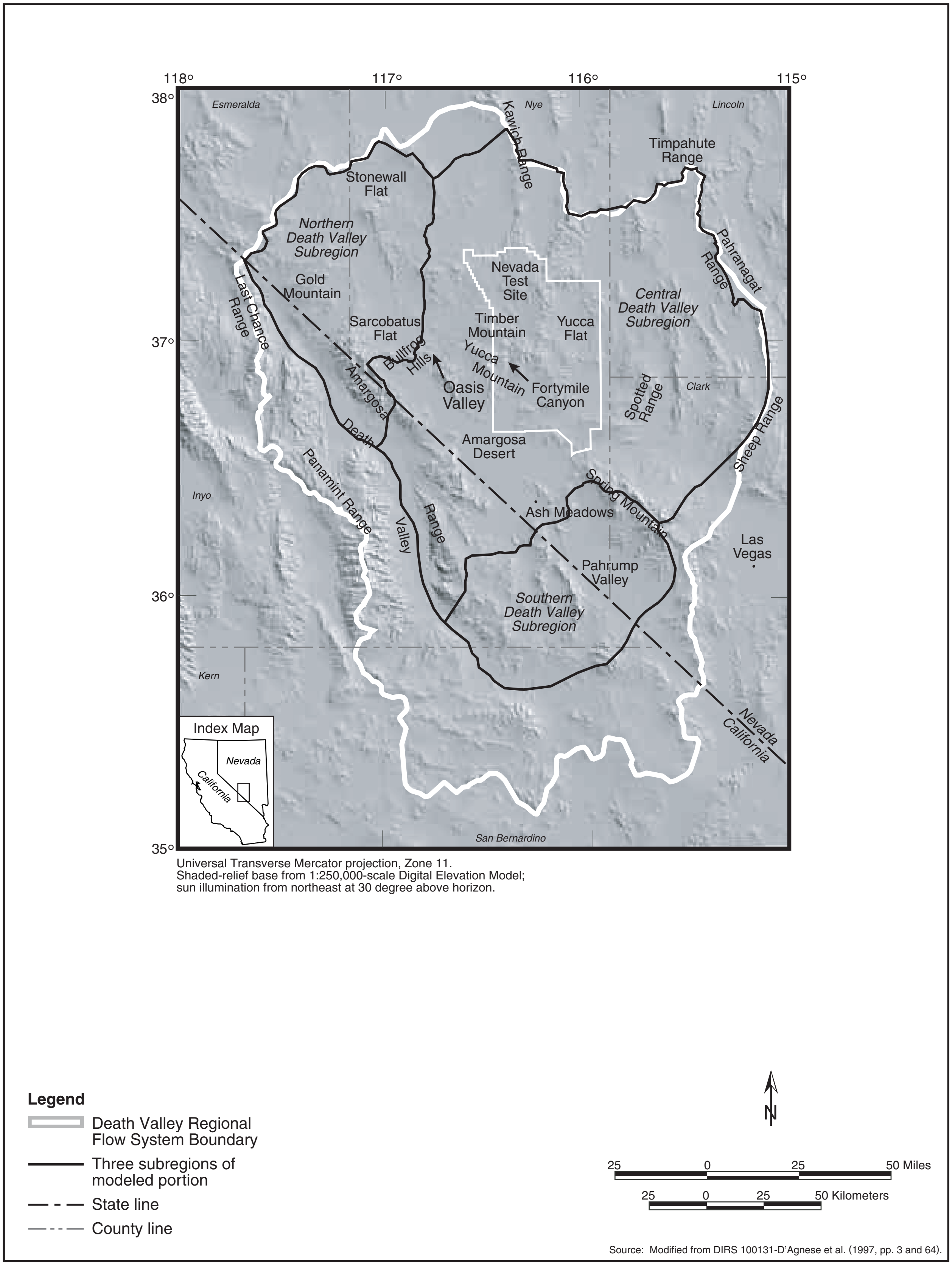

Figure 3-13. Boundaries of Death Valley regional groundwater flow system.

Universal Transverse Mercator projection, Zone 11. Shaded-relief base from 1:250,000-scale Digital Elevation Model; sun illumination from northeast at 30 degrees above horizon

Legend

Death Valley Regional flow system boundary

1,000 Potentiometric contour - show altitude of potentiometric surface. Contour interval 100 meters. Datum is sea level.

N

25 0 25 Kilometers

25 0 25 Miles

Source: Modified from DIRS 100131-D'Agnese et al. (1997, Figure 27).

Figure 3-14. Estimated potentiometric surface of the Death Valley region.

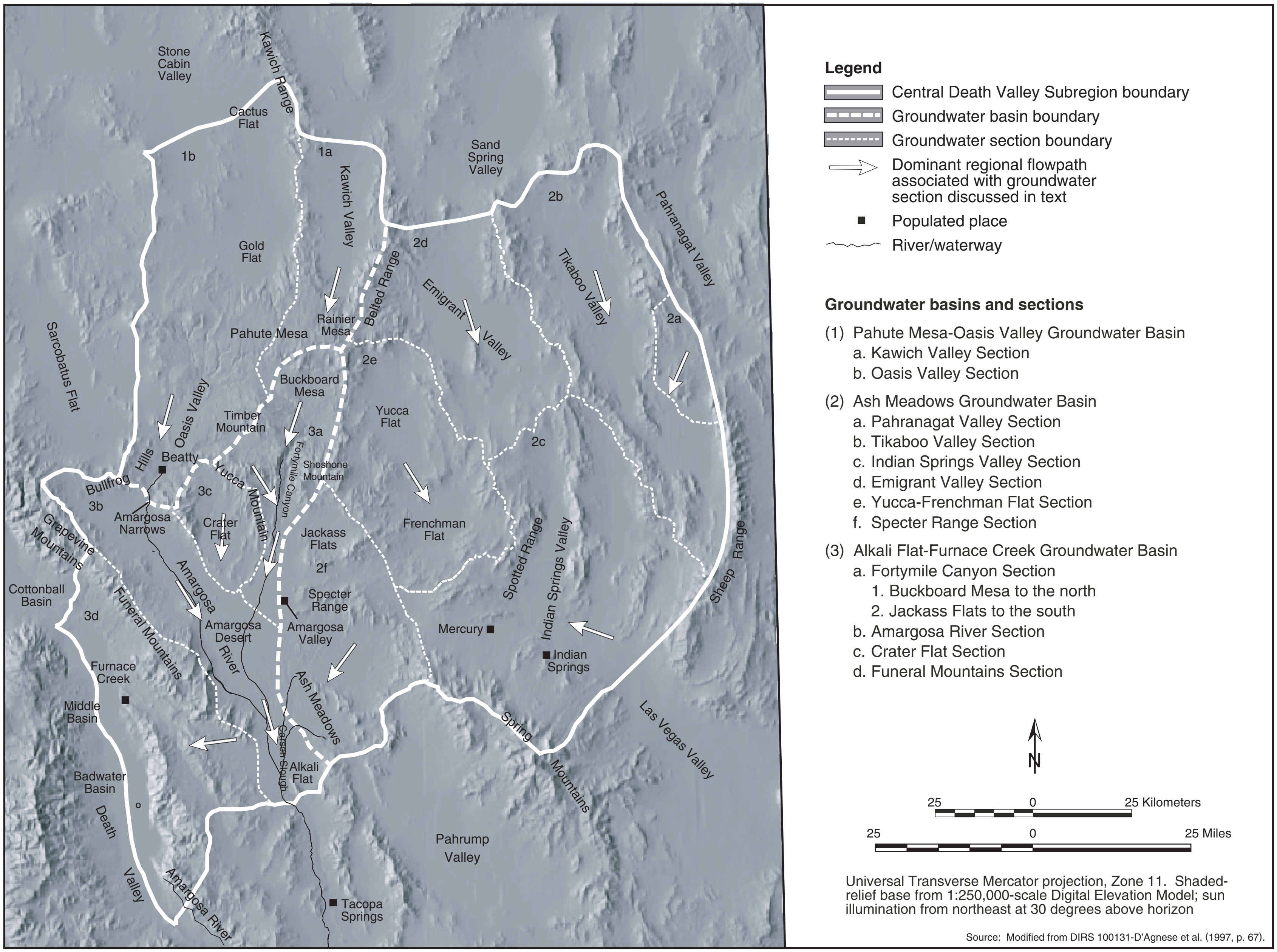

Figure 3-15. Groundwater basins and sections of the Central Death Valley subregion.

The Ash Meadows groundwater basin is the easternmost of the three basins that make up the Central Death Valley subregion. It underlies eastern portions of the Nevada Test Site (Yucca Flat, Frenchman Flat, Mercury Valley, Rock Valley), parts of Shoshone Mountain, Rainier Mesa to the north, and the Ash Meadows area of the Amargosa Desert in the south. Inflow is principally from the Spring Mountains, Pahranagat Range, Sheep Range, and Pahranagat Valley in the eastern portion of the basin (DIRS 100131-D'Agnese et al. 1997, pp. 67 and 68). Outflow is basically in the form of discharge to the surface and underflow to the lower portion of the Alkali Flat-Furnace Creek groundwater basin. The primary discharge point for this groundwater basin is Ash Meadows, where springs occur in a line along a major fault (DIRS 151945-CRWMS M&O 2000, p. 9.2-17). Estimates of discharge at Ash Meadows range from 21 million to 37 million cubic meters (17,000 to 30,000 acre-feet) per year (DIRS 103022-Walker and Eakin 1963, p. 24; DIRS 100131-D'Agnese et al. 1997, p. 46).

The Pahute Mesa-Oasis Valley groundwater basin includes Oasis Valley, Gold Flat, the southern parts of Cactus Flat and Kawich Valley, and the western portion of Pahute Mesa. Recharge areas are primarily in the north in the Belted and Kawich Ranges and Pahute Mesa, but include Timber Mountain and the Bullfrog Hills, and along the Amargosa River and its tributaries (DIRS 151945-CRWMS M&O 2000, p. 9.2-17). Subsurface outflow is into the Amargosa Desert of the Alkali Flat-Furnace Creek groundwater basin, and has been estimated at about 0.49 million cubic meters (400 acre-feet) per year (DIRS 106695-Malmberg and Eakin 1962, p. 26).

The Alkali Flat-Furnace Creek groundwater basin is bordered on the northwest by the Pahute Mesa-Oasis Valley basin and on the east by the Ash Meadows basin. This groundwater basin includes portions of the Nevada Test Site (parts of Rainier Mesa, Pahute Mesa, and Buckboard Mesa to the north, Shoshone Mountain, Yucca Mountain, and Jackass Flats in the southern half), Crater Flat in the west, and part of Death Valley and the central part of the Amargosa Desert in the south (DIRS 100131-D'Agnese et al. 1997, pp. 67 to 69). As shown in Figure 3-15, this basin includes the groundwater area designated as the Fortymile Canyon Section, which includes the area of Buckboard Mesa to the north and a portion of Jackass Flats to the south. Groundwater moving beneath the proposed repository site is in the Fortymile Canyon section.

In the immediate vicinity of Yucca Mountain, sources of recharge to the groundwater include Fortymile Wash and precipitation that infiltrates the surface. However, these local sources are not among the primary sources of recharge in the area that makes up the Alkali Flat-Furnace Creek groundwater basin. The primary sources of surface recharge in this area are infiltration on Pahute Mesa, Rainier Mesa, Timber Mountain, and Shoshone Mountain to the north (DIRS 151945-CRWMS M&O 2000, p. 9.2-18), and the Grapevine and Funeral Mountains to the south (DIRS 100131-D'Agnese et al. 1997, p. 68). One numerical model of infiltration for Yucca Mountain used energy- and water-balance calculations to obtain an average infiltration rate of 4.7 millimeters (0.2 inch) a year over the potential repository area for the current climate (DIRS 151945-CRWMS M&O 2000, Table 8.2-9, p. T8.2-7). This represents less than 3 percent of an average annual precipitation rate of about 200 millimeters (8 inches) used in the model for the crest at Yucca Mountain. In comparison, areas such as Pahute Mesa, Timber Mountain, and Shoshone Mountain receive more precipitation (DIRS 103021-DOE 1997, Plate 1) and have higher estimated percentages of precipitation infiltrating deep into the ground and eventually becoming recharge to the aquifer.

Water infiltrating at Yucca Mountain and becoming recharge to the groundwater would join with water in the Fortymile Canyon Section (Figure 3-15). From there the general direction of groundwater flow is to the Amargosa Desert basin and then Death Valley (DIRS 151945-CRWMS M&O 2000, p. 9.2-18). There have been many estimates of the amount of groundwater moving along this path. One study (DIRS 103016-State of Nevada 1971, p. 50) that is still used extensively by the State of Nevada in its groundwater planning efforts estimated annual groundwater movement of 10 million cubic meters (8,100 acre-feet) from the area of Jackass Flats to the Amargosa Desert and 23.4 million cubic meters

(19,000 acre-feet) from the Amargosa Desert to Death Valley. DOE studies indicate that the quantity of water that might move through a repository area of 10 square kilometers (2,500 acres) (the largest repository footprint under any of the operating modes), assuming 4.7 millimeters (0.2 inch) of infiltration per year, would be about 0.2 percent of the estimated 23.4 million cubic meters (19,000 acre-feet) that moves from the Amargosa Desert to Death Valley on an annual basis.

DOE has performed a study (DIRS 157072-BSC 2001, all) to develop an "expected-case" model of groundwater flow in the saturated zone from beneath Yucca Mountain. The primary objective of the study was to evaluate the effects of several specific elements of conservatism in the groundwater flow model used in the Total System Performance Assessment (TSPA; see Chapter 5 and Appendix I). The study looked at the physical parameter values used in that model, for example the diffusion coefficient, porosity for fractured tuffs, and *permeability* for alluvial materials. It also looked at the location assumed in the TSPA where the groundwater flow path in the saturated zone changes from tuff to alluvial material. The recent effort looked at data collected on several specific parameters that would support what were felt to be more realistic, less conservative values. The expected-case model was run with these parameters changed and assuming a nonsorbing tracer was released as a point source to the water table beneath the proposed repository. The results of these model runs indicated it would take in the range of 1,000 to 1,500 years for 50 percent of the tracer to reach a distance of 20 kilometers (12 miles) in the groundwater flow path (DIRS 157072-BSC 2001, Figure 10, p. 43). Some of the tracer would find its way to faster pathways; some would take longer to travel the distance. DOE believes these estimates of groundwater travel time in the saturated zone represent reasonable estimates of what occurs in the natural setting.

As water in the Alkali Flat-Furnace Creek groundwater basin moves south through the Amargosa Desert, eastern portions of the flow are joined by underflow from the Ash Meadows groundwater basin (DIRS 101779-DOE 1998, Volume 1, pp. 2-56 to 2-58). The line of springs formed by discharge from the Ash Meadows groundwater basin provides much of the boundary between the two basins (DIRS 151945-CRWMS M&O 2000, p. 9.2-17). In this area there is a marked decline of about 64 meters (210 feet) in water table elevation between Devils Hole and Carson Slough, approximately 6.4 kilometers (4 miles) to the west (DIRS 103415-Dudley and Larson 1976, p. 23). This elevation decline indicates that the potential groundwater flow is from Ash Meadows toward the Alkali Flat-Furnace Creek groundwater basin, rather than the opposite. The primary groundwater discharge point for this groundwater basin is Alkali Flat (Franklin Lake Playa) as indicated by the potentiometric surface (or slope) of the groundwater and hydrochemical data. A small portion could move toward discharge points in the Furnace Creek area of Death Valley (DIRS 151945-CRWMS M&O 2000, p. 9.2-18).

Different researchers have speculated that the general flow boundaries of the three groundwater basins in the Central Death Valley subregion are in slightly different locations (DIRS 100131-D'Agnese et al. 1997, p. 59). Some studies [for example, DIRS 101062-Waddell (1982, p. 15)] have placed the Kawich Valley area in the Alkali Flat-Furnace Creek groundwater basin rather than in the Pahute Mesa-Oasis Valley groundwater basin as shown in Figure 3-15. This uncertainty in general flow boundaries is a reflection of the complex groundwater flow systems in the Death Valley region. The differing interpretations of the groundwater basin boundaries do not, however, disagree on the relative location of the aquifers below Yucca Mountain, which are consistently placed in the central Alkali Flat-Furnace Creek basin.

To reduce uncertainties, studies of the regional groundwater flow system are continuing. This is particularly true of that portion of the flow system that is downgradient of Yucca Mountain. Nye County, under a Cooperative Agreement with DOE, has implemented the Early Warning Drilling Program to install a series of wells in the Amargosa Valley area and the southern part of the Nevada Test Site. The purpose of this program is to characterize and monitor the saturated zone along possible transport pathways from Yucca Mountain. At the time this document was prepared, plans were underway to extend this program, which was originally set at 3 years (with a scheduled end date of November 2001). Under terms of the agreement, Nye County has had the responsibility to drill, test, and monitor a series of shallow and deep wells to investigate the upper volcanic or alluvial aquifers and the deep carbonate aquifer. The objective of the work is to determine aquifer characteristics, water chemistries, and flow paths. The County provides DOE splits of all samples collected and copies of all data obtained. DOE will continue to study the saturated zone south of Yucca Mountain through the simultaneous collection of data from this program and the use of data obtained by Nye County. In addition, a set of wells will be installed in Fortymile Wash to help identify the extent of the alluvium and valley fill along the potential flow path. Some of these wells will also be used to support an Alluvial Testing Complex, where aquifer and tracer tests in the alluvium and valley fill will be conducted. DIRS 156115-NWRPO (2001, all) described its efforts for Fiscal Years 1996 to 2001 in an August 2001 report prepared for DOE. Some of the groundwater findings discussed in this report include the following:

- Valley-fill deposits in the Amargosa Desert Area are very complex. Subsurface investigations have shown evidence of groundwater compartments as a result of faulting in the underlying rock. The conceptual hydrogeological model being developed from this information suggests that these compartments and boundaries between compartments serve either as groundwater flow pathways or as barriers. However, with several exceptions, the number and locations of compartments have not yet been well defined.

- Water level monitoring and temperature logs in wells suggest an upward gradient from underlying carbonate basement rocks into overlying valley-fill sediments.

- Evidence of transient (that is, varying over time) flow conditions in the past 50 years suggests it might be appropriate to calibrate groundwater flow models to transient flow conditions rather than the assumed steady-state conditions.

Although the Nye County report discusses these and other findings, Nye County and DOE have shared test results and data throughout the program. DOE has used and will continue to use the data collected from the Nye County and alluvial testing programs to refine its understanding of flow and transport mechanics south of Yucca Mountain. The information gained from these and other studies will be used to evaluate the accuracy and adequacy of similar information used in assessing the long-term performance of the proposed repository. The new information will also be used, as appropriate, in future iterations of conceptual and numerical models supporting the long-term performance assessment (see Chapter 5).

Use. Table 3-11 summarizes groundwater use in the Yucca Mountain region. The *hydrographic areas* listed in the table are basically a finer division of the subregions and groundwater basins discussed above; their locations are roughly consistent with the sectional divisions shown in Figure 3-15. These locations do not precisely match the groundwater area designations described in the preceding discussion because hydrographic areas generally reflect topographic divides (such as mountain ranges and valleys) that in some cases do not correspond to divides based on groundwater movement. The hydrographic area designations are important because the State of Nevada uses them as the basic units in its water planning and appropriations efforts.

DOE has been using small amounts of Jackass Flats hydrographic area groundwater for Nevada Test Site operations, and Yucca Mountain activities have contributed to water use from this source. Most water use in the Alkali Flat-Furnace Creek groundwater basin, however, occurs south of Yucca Mountain, from the Amargosa Desert alluvial aquifer (DIRS 151945-CRWMS M&O 2000, p. 9.2-23). Between 1985 and 1992, water use in the Amargosa Desert from this aquifer averaged 8.1 million cubic meters (6,600 acre-feet) a year for agriculture, mining, livestock, and domestic purposes (DIRS 147766-Thiel 1999, p. 15).

Table 3-11. Perennial yield and water use in the Yucca Mountain region.

Hydrographic area[a]	Perennial yield[b,c] (acre-feet per year)[d]	Current appropriations[e,c] (acre-feet per year)	Average annual withdrawals 1995-1997 (acre-feet)	Chief uses
Jackass Flats (Area 227a)	880[f] - 4,000	500[g]	340[h]	Nevada Test Site programs and site characterization of Yucca Mountain. Minor amounts of water are also discharged for tests at Yucca Mountain.
Crater Flat (Area 229)	220 - 1,000	1,200[i]	140[j]	Mining, site characterization of Yucca Mountain
Amargosa Desert (Area 230)	24,000 - 34,000	27,000	14,000[j]	Agriculture, mining, livestock, municipal, wildlife habitat
Oasis Valley (Area 228)	1,000 - 2,000	1,700	N/A[k]	Agriculture, municipal

a. A specific area in which the State of Nevada allocates and manages the groundwater resources. See Figure 3-20.
b. The quantity of groundwater that can be withdrawn annually from a groundwater reservoir, or basin, for an indefinite period of time without depleting the reservoir; also referred to as *safe yield*.
c. Sources: DIRS 147766-Thiel (1999, p. 5-12); perennial yield values only, DIRS 101811-DOE (1996, pp. 4-117 and 4-118).
d. An *acre-foot* is a commonly used hydrologic measurement of water volume equal to the amount of water that would cover an acre of ground to a depth of 1 foot. To convert acre-feet to cubic meters, multiply by 1,233.49; to convert to gallons, multiply acre-feet by 325,851.
e. The amount of water that the State of Nevada authorizes for use; the amount used might be much less. These appropriations do not cover Federal Reserve Water Rights held by the Nevada Test Site or Air Force.
f. The low estimate for perennial yield from Jackass Flats breaks the quantity down further into 300 acre-feet for the eastern third of the area and 580 acre-feet for the western two-thirds.
g. Area 227a appropriations include about 370 acre-feet for Yucca Mountain characterization activities.
h. Source of Area 227a withdrawals: DIRS 101486-Bauer et al. (1996, p. 702) and DIRS 103090-Bostic et al. (1997, p. 592) for withdrawals from wells J-12 and J-13 at the Nevada Test Site.
i. Area 229 appropriations include temporary mining rights and 61 acre-feet for Yucca Mountain characterization activities.
j. Sources of Area 229 and 230 withdrawals: DIRS 102890-La Camera, Westenburg, and Locke (1996, p. 74) and DIRS 103011-La Camera and Locke (1997, p. 77).
k. N/A = not available.

As Table 3-11 indicates, water use averaged about 17 million cubic meters (14,000 acre-feet) a year from 1995 through 1997. As listed in Table 3-11, groundwater in the Amargosa Desert is heavily appropriated—at much higher levels than is actually withdrawn.

The Ash Meadows area of the Amargosa Desert has restrictions on groundwater withdrawal as a result of a U.S. Supreme Court decision (DIRS 148102-Cappaert v. United States 1976, all) to protect the water level in Devils Hole. Devils Hole became a National Monument in 1952 to preserve the Devils Hole pupfish and the pool in which the fish live. The pool contains a rock shelf that is critical to the survival of the Devils Hole pupfish because it provides an area for the fish to feed and spawn. Withdrawal of water from the connected aquifer has caused the water level in the pool to decline. The Supreme Court found that an existing Federal water right precluded development of the aquifer to the extent that the water level in the pool be maintained at a level providing adequate coverage of the rock shelf and, thereby, providing the necessary habitat for the pupfish. The Ash Meadows National Wildlife Refuge (see Figure 3-11), which includes the Devils Hole area, was established in 1984 (see Section 3.1.5.1.3). As noted above in the discussions of basins and regional groundwater movement, groundwater flowing beneath Yucca Mountain does not contribute to the groundwater beneath the area of Ash Meadows. However, the slope of the water table from Ash Meadows to the Amargosa Desert could be affected by changes in the Desert's water table elevation.

Table 3-11 lists water volumes (*perennial yield*, appropriations, and withdrawals) in acre-feet. This unit of volume is common in hydrology and water resource planning. This EIS describes water volumes in both metric (cubic meters) and English (acre-feet) units.

Groundwater Quality. The U.S. Geological Survey has accumulated and evaluated almost 90 years of groundwater data for the Yucca Mountain region and, in more recent years, has periodically collected and analyzed groundwater quality samples (DIRS 104986-CRWMS M&O 1999, pp. 6 to 9). A recent sampling effort (DIRS 104828-Covay 1997, all) looked for a wide range of inorganic and organic constituents, as well as general water quality properties. This effort collected samples from five groundwater sources in the Amargosa Desert region and three from the immediate vicinity of Yucca Mountain (as discussed in Section 3.1.4.2.2). The regional sampling locations included two wells in the central Amargosa Desert, one well in the Ash Meadows area, and two springs along the border between the Alkali Flat-Furnace Creek and Ash Meadows groundwater basins. Selected results from the recent groundwater sampling effort are listed in Table 3-12.

Table 3-12. Concentrations of selected water quality parameters in the regional groundwater.[a,b,c]

Parameter	Range of reported concentrations (milligrams per liter)	Parameter	Range of reported concentrations (milligrams per liter)
Aluminum	0.0021 - 0.0049	Lead	<0.001 - 0.0013
Antimony	<0.001 (all)	Manganese	<0.001 - 0.0022
Arsenic	0.008 - 0.022	Mercury	<0.0001 (all)
Barium	0.0012 - 0.067	Molybdenum	0.0027 - 0.010
Beryllium	<0.001 (all)	Nickel	<0.001 (all)
Boron	0.114 - 1.06	Nitrite	<0.010 (all)
Cadmium	<0.001 (all)	Nitrite plus nitrate	<0.050 - 2.17
Chloride	6.6 - 100	Selenium	<0.001 - 0.019
Chromium	0.0022 - 0.0065	Silver	<0.001 (all)
Copper	<0.001 - 0.001	Strontium	0.041 - 1.53
Cyanide	<0.01 (all)	Sulfate	18 - 420
Fluoride	1.6 - 2.3	Thallium	<0.0005 (all)
Iron	<0.003 - 0.014	Total dissolved solids (TDS)	217 - 1,110
Organochlorine and organonitrogen compounds (analysis for 45 constituents)	None detected[d] (0.00001 - 0.001)	Zinc	<0.001 - 0.027
Volatile organic compounds (analysis for 60 constituents)	None detected[d] (0.001 - 0.006)	Semivolatile organic compounds (analysis for 57 constituents)	None detected[d] (0.003 - 0.040)

a. Source: DIRS 104828-Covay (1997, all).
b. Samples collected in May 1997 from eight locations (five in the Amargosa Desert region and three in the vicinity of Yucca Mountain).
c. Parameters selected for display are primarily those identified in EPA's Primary and Secondary Drinking Water Standards.
d. "None detected" indicates no results were above the analytical laboratory's detection limits. The range of reported detection limits is in parentheses.

The U.S. Geological Survey effort compared the regional groundwater quality measurements to the primary and secondary drinking water standards established by the Environmental Protection Agency [DIRS 104876-EPA 1993, all; see also the Safe Drinking Water Act, as amended, 42 U.S.C. 300(f) *et seq.*]. Though drinking water standards are for public water supply systems, it is common to compare results from groundwater sampling and analysis to these standards for an indication of groundwater quality. The findings indicated that the five groundwater sources met primary drinking water standards, but that a few sources exceeded secondary and proposed standards. Specifically, four of the wells exceeded a proposed standard for radon (Section 3.1.8.2 discusses the natural occurrence of radon in the Yucca Mountain region) and one of those four exceeded secondary standards for sulfate and total dissolved solids and a proposed standard for uranium. Overall, however, regional groundwater quality is generally good and consistent with the State of Nevada description that most groundwater aquifers in the State are suitable, or marginally suitable, for most uses (DIRS 148164-NDWP 1999, all). Additional water quality data for wells on the Nevada Test Site are available in the *Final Environmental Impact*

Statement for the Nevada Test Site and Off-Site Locations in the State of Nevada (DIRS 101811-DOE 1996, pp. 4-124 to 4-126). Section 3.1.4.2.2 discusses radiological parameters, including results from regional sample locations.

3.1.4.2.2 *Groundwater at Yucca Mountain*

Groundwater at Yucca Mountain occurs in an unsaturated zone and a saturated zone. This section describes these zones and the characteristics of the groundwater in them.

SUBSURFACE FORMATIONS CONTAINING WATER

Unsaturated zone: The zone of soil or rock between the land surface and the *water table.*

Saturated zone: The region below the *water table* where rock pores and *fractures* are completely saturated with *groundwater*.

Perched water bodies: Saturated lenses (thin layers of water) surrounded by unsaturated conditions.

Unsaturated Zone

Water Occurrence. The unsaturated zone at Yucca Mountain extends down from the crest of the mountain about 750 meters (2,500 feet) to the water table (the upper surface of the saturated zone) (DIRS 151945-CRWMS M&O 2000, p. 8.1-1). The primary emplacement area (the upper block) of the proposed repository would be in the unsaturated zone, at least 160 and up to 400 meters (530 up to 1,300 feet) above the present water table (DIRS 151945-CRWMS M&O 2000, p. 9.4-1). The excavation of the Exploratory Studies Facility, including the Enhanced Characterization of the Repository Block *Cross-Drift*, involved more than 11 kilometers (8.4 miles) of tunnels and testing alcoves. Throughout this excavation, only one fracture was observed to be moist (DIRS 154565-Levich et al. 2000, p. 404); there was no active flow of water. Boreholes in the unsaturated zone identified water in the rock matrix, along faults and other fractures, and in isolated saturated zones of *perched water* (DIRS 151945-CRWMS M&O 2000, p. 8.5-1) (Figure 3-16). The water found in the pores of the rock matrix is chemically different from water found in fractures, perched water, or water in the saturated zone (DIRS 151945-CRWMS M&O 2000, pp. 8.6-1 and 8.6-2). Perched water in Yucca Mountain occurs where fractured rock overlies rock of low permeability such as unfractured rock, and upslope from faults where permeable or fractured rock lies against less permeable rock and fault fill material. Perched water bodies occur approximately 100 to 200 meters (330 to 660 feet) below the proposed repository horizon near the base of the Topopah Spring welded tuff unit (DIRS 151945-CRWMS M&O 2000, p. 8.5-10) (Figure 3-16). Water flow along fractures probably is responsible for recharging the perched water bodies. The apparent age of the perched water based on carbon-14 dating shows residence times of 3,500 to 11,000 years (DIRS 151945-CRWMS M&O 2000, p. 8.6-3). Although there are limitations in the use of carbon-14 dating on water (such as knowing the initial activity of carbon-14, estimating sources of losses or gains, and adjusting for postnuclear age contributions), the perched water is believed to be too recent to be an accumulation of pore water from the rock matrix. Water chemistry data (discussed below) that show the perched water with different characteristics than the pore water provide additional, possibly stronger, evidence that pore water does not contribute significantly to the perched water. To learn how recently recharge might have occurred, these dating efforts also looked for the presence of tritium, which would indicate contributions from water affected by atmospheric nuclear weapons tests (after 1952). The results indicate that if tritium has reached the perched water bodies, it is in quantities too small for reliable detection (DIRS 151945-CRWMS M&O 2000, p. 5.3-30).

Hydrologic Properties of Rock. The unsaturated zone at Yucca Mountain consists of small areas of alluvium (clay, mud, sand, silt, gravel, and other detrital matter deposited by running water) and colluvium (unconsolidated slope deposits) at the surface underlain by volcanic rocks, mainly fragmented